SUPPLEMENTAL APPENDENDIX -- E

BAND SHARING COORDINATION
OF WIDE-BAND CDMA MOBILE SATELLITE SERVICES

By
Dr. Albert John Mallinckrodt*

The Federal Communications Commission (FCC) has before it the consideration of multiple proposals for mobile satellite service. These proposals have in common the recognition of the UHF bands, roughly 800 to 3000 MHz as broadly optimum for the satellite-to-mobile-user, and return links. That limited open space in this band has thus naturally become a precious commodity.

At the same time, there has developed, among FCC and the proposers, a wide spread (but not yet universal) recognition of the potential advantages of Spread Spectrum Code Division Multiple Access (SSCDMA) in making most effective use of this precious spectrum. (See, e.g., Section 25.141(f) of the Commission's rules and regulations, 47 C.F.R. §25.141(f).) As a result FCC has several SSCDMA MSAT proposals, some of these implying an unqualified ability to share the allocated band with other system proposers. Motorola, on the other hand has put forth arguments that their FDMA system provides a more efficient means either alone, or band sharing on an FDMA frequency basis. Neither such extreme position is technically correct.

CELSAT is strongly aware of, and firmly committed to the advantages of SSCDMA for efficient band utilization. Celsat's proposed system is based on that technology. However, those advantages are not without limiting qualifications. The uncluttered spectrum is not a bottomless well that can satisfy the thirst of all who would come to drink, even with the advantages of CDMA. Thus in considering CDMA multiple band sharing proposals, it may become incumbent upon FCC to devise means of allocating flux spectral density as well as frequency bands. This Supplemental Appendix to CELSAT's Petition for Rulemaking, RM-7927 develops the fundamental technical limitations on band sharing and their relation to individual system and overall spectral efficiency, in the particular context of the multiple band entry MSS/RDSS allocation problem. In the process it develops criteria that may be of use to the FCC in deciding how best to allocate and manage such common function, multiple entry band sharing allocations. And finally, it serves as the basis for a specific further proposed rule amendment to Part 25 by which licensees in the RDSS and other bands might reasonably share spectrum most efficiently.

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CODE CORRELATION

Band sharing SSCDMA users potentially interfere with one another in two ways. The first and easier part of the coordination problem is Code Correlation. In order to effectively to separate the various band sharing signals, the spreading codes must be essentially "uncorrelated". If two users were to utilize identical band spreading pseudo-noise waveforms or codes, they would interfere with each other totally, as if they were FDMA users in the same frequency channel.

Ideally, all user codes would be orthogonal, that is, correlation would always be zero. But this can easily be shown to be impossible, both because of the limited number of such orthogonal codes, and because orthogonal codes are only so at a particular relative phasing with respect to one another. In the MSAT service, the relative phases of signals from different sources are position dependent. So a set of codes that were orthogonal in one location would not generally be so in another. Practically, to realize the full advantages of SSCDMA band sharing, users must utilize codes that do not correlate more strongly than random noise of the same power and bandwidth. This decorrelation can be effected by the use of "sufficiently" (can be rigorously defined) different code generators, frequencies, or phases. Considering these dimensions, there are potentially far more than enough pseudo-random spreading waveforms to go around, given some minimal structured coordination.

SELF- AND MUTUAL RANDOM CODE INTERFERENCE

The second aspect is more difficult and relates to control of cumulative background interference level. Each band sharing user, CDMA or otherwise, contributes his signal power spectrum at the receiver to the general random, Gaussian noise-like background as seen by every other CDMA receiver. When the cumulative density effect of all such band-sharing users exceeds the natural thermal noise background by more than a few dB, then the band is effectively saturated; practically, no more band sharing is possible. To introduce more band sharers or for any one user to attempt to increase his capacity by amplifying his signal level above this general background can only lead to an ultimately non-productive, mutual escalation of transmitter power without any gain in signal/noise ratio. We will develop the fundamental governing relations for this band sharing limitation hierarchically,

starting with a single CDMA circuit,
then a single CDMA cell,
then a single regional CDMA system of cells,
then a summation of regional CDMA (or other) systems,

all sharing a common spreading bandwidth, W.

SINGLE CIRCUIT

First consider a lone circuit, with no intra- or inter- system interference from other users. The transmitted signal is idealized as uniformly spread over a bandwidth W with power areal-spectral density at the mobile unit, ρ_1 (w/m²/Hz). Then the available[1] signal power S_1 at the user antenna terminals can be expressed as

$$S_1 = \rho_1 A W \quad \text{(W/Hz)}$$

where

A = user receive antenna capture, area

$\equiv G_r \lambda^2 / 4\pi$

In the present instance we are dealing with systems all of which are designed to serve mobile, handset users. Consequently it is not unreasonable to assume that all the competing systems have about the same antenna gain (about zero dB +/-) and, of course, all are operating at the same wavelength, λ. We thus take A, as a system independent constant for most mobile satellite systems in given band (AMSC may be a mild exception).

The available[1] system noise power spectral density at the same terminals may be expressed

$$N_o = k T_o NF$$

where

$k T_o$ = reference temperature thermal noise spectral density (W/Hz)

NF = Effective system noise figure including external noise (other than CDMA interference)

All of the systems of interest are digital at the baseband, so the relevant SNR-like parameter is the dimensionless bit energy-to-noise-density ratio, $\gamma = E_b/N_o$ given by

$$\gamma = S_1 / (N_o R) = \rho_1 A W / (N_o R)$$

where R is the baseband digital rate.

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[1]. The term "available" here means the maximum power available from the antenna to a matched load.

To meet a suitable BER criterion, γ is required to satisfy a certain minimum value, Γ_s, characteristic of the particular system (subscript s), typically 4 to 9 dB depending on details of modulation and coding. So we can solve for the required flux spectral density for a single circuit with no interference,

$$\rho_{1,s} = \Gamma_s N_o R / (A W).$$

Notation can be further simplified by defining an effective thermal noise equivalent flux density,

$$\rho_n = N_o / A$$

For a relevant example, consider N_o = kTo = -204.0 dBW/Hz, (i.e. thermal noise only), omnidirectional antenna at 2400 MHz. A = -29.0 dBm^{-2} and ρ_n = -138.9 $\mathrm{dBW/m^2/4kHz}$. The high angle ITU flux limit, -144 $\mathrm{dBW/m^2/4kHz}$ is thus 5 dB less than the noise equivalent flux, making it generally negligible, as surely intended, for this kind of service.

In these terms, the required flux density for a single signal can be written:

$$\boxed{\rho_{1,s} = \rho_n \, \Gamma_s \, \frac{R}{W} \qquad (1)}$$

In words, the minimum flux density for a single data channel is equal to the product of the equivalent noise flux density times the required Eb/No divided by the bandspread ratio, or processing gain, W/R.

SINGLE CDMA CELL

Now suppose that only one cell of one system is on the air. The system is subject to a flux density limit, ρ_s at the earth. How many circuits, M_s, can the system support in this one cell?

The thermal noise in this case is augmented by the CDMA noise from the other M_s - 1 circuits in the system. M_s is then given by the equivalent of Equation 1 above in which we substitute

ρ_s / M_s for $\rho_{1,s}$ (the single signal flux density) and

$\rho_n + \rho_i$ for ρ_n

where

ρ_i = Interference flux spectral density

$\equiv (M_s - 1) / M_s \, \rho_s$

Since M_s, the number of circuits per system is generally much greater than 1 in the cases of interest, there is little error in assuming that the factor $(M_s - 1) / M_s$ is equal to 1. With these substitutions,

$$\Gamma_s = \frac{\rho_s}{(\rho_n + \rho_i)} \frac{W}{M_s R}$$

or

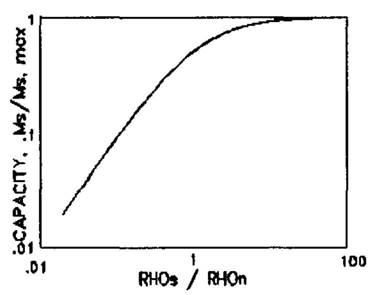
$$M_s = \frac{\rho_s}{(\rho_n + \rho_i)} \frac{W}{\Gamma_s R} \qquad (2)$$

$$\boxed{M_s = \frac{\rho_s}{(\rho_n + \rho_s)} M_{max,s} \qquad (3)}$$

where

$M_{max,s} \equiv W / (\Gamma_s R)$

This looks like this ----> > > >



For small ρ_s the capacity is proportional to ρ_s, that is, ultimately proportional to transmitter power. But as ρ_s becomes much larger than ρ_n, (the noise equivalent flux density) the maximum number of circuits supported approaches the limiting constant,

$M_s \rightarrow M_{max,s}$

independent of ρ_s or transmitter power. Further increases in power, or total flux density, ρ_s are unproductive in increasing system capacity since they raise the interference level as fast as the desired signal. Thus, $M_{max,s} = W / (\Gamma_s R)$, is the limiting CDMA circuit capacity of this simple, single cell example.

Some CDMA critics have noted that W/R is essentially the capacity of the same channel under Frequency Division Multiplex, and that therefore the limiting capacity of CDMA is smaller than FDMA by the factor $1 / \Gamma_s$. This would be true for a single cell system, (such as Irridium with respect to US coverage) but ignores the much larger gain in capacity due to frequency reuse factor that results from the unique CDMA ability to reuse the same spectrum in *each* cell in a multiple cell coverage system like CELSAT.

SINGLE-SYSTEM, MULTIPLE-CELL REGIONAL COVERAGE

Generally, system regional capacity over an area such as the United States, can be increased by the use of multiple smaller beams covering the region with a multiplicity of smaller contiguous beams, that is, "cells". This provides a potential twofold advantage, 1) higher antenna gain, thus more total flux density for the same, limited transmitter power, and, 2) opportunity for reuse of the same spectrum in another part of the region. Both factors tend to increase the total regional circuit capacity. Let $\mathbf{NCR_s}$ = Number of Cells per Region for system, s (e.g. United States).

Frequency reuse among these cells, like co-channel reuse, comes at the cost of some additional co-channel interference. In general, and particularly in the case of FDMA where relatively little co-channel interference can be tolerated, it is necessary to put some distance between co-channel users. The required distance separation in turn implies a "cluster size", $\mathbf{NCC_s}$, (Number-of-Cells-per Cluster) which is defined as the minimum number of neighboring cells, each operating within a *different* subband, such that there be no co-channel interference between cluster members and that any cell outside the cluster is far enough away from a co-channel user within the cluster that his interference is tolerable. In the case of ground cellular users this cluster size is typically 7 or more. In the case of satellite systems, depending on the multiplex mode, cluster sizes range from 1 to 7.

A second important factor in consideration of regional coverage is "beam overlap factor", **OF**. It is possible in the case of CDMA to reuse the same frequency bands in every cell, that is, a cluster size of one. However, this is then at the price of possibly significant beam overlap or sideband spillover from one cell to the next. The effect of this spillover is a correspondingly increased background interference level and reduced circuit capacity. On the assumption of uniform loading of all cells, knowing the beam pattern, we can compute the amount of such spillover. We then define:

BOF = **Beam Overlap Factor**

= (Total CDMA interference flux from all co-channel users in ***all*** cells)/ (CDMA interference flux from all co-channel users in ***own*** cell) for CDMA systems

For the CELSAT downlink, the cell major radius is set to correspond to the 3 dB point on the antenna pattern which has been found broadly optimum, and the resulting calculated overlap factor is 2.4 times or about 3.8 dB. In other words, the total interference is equivalent to that from about 2.4 times as many users as the actual cell traffic. With cells in a regular hexagonal grid and 3 dB major diameter crossover it is also roughly constant at all positions within a given cell.

If the system is subject to a maximum flux density limit, ρ_{ms}, then the total interference flux is ρ_{ms}, while the signal flux is ρ_{ms}/OF

With these definitions, the per cell capacity is given by (2) above with the substitutions:

W/NCC_s for W (Only 1/NCC of the total bandwidth is used per cell) and

ρ_{ms} for ρ_i (total interference limit)

ρ_{ms}/BOF_s for ρ_s (only the own cell useful part of the total flux)

and the total regional capacity, M_r is:

$$\boxed{M_{r_s} = \frac{\dfrac{\rho_{m_s}}{BOF_s} RFRF_s M_{\max,s}}{\rho_n + \rho_{m_s}} \qquad (4)}$$

where

$RFRF_s$ $\triangleq$ Regional Frequency Reuse Factor for system s

$\triangleq$ NCR_s/NCC_s

For non-CDMA systems, essentially the same equation holds with the following understandings: 1) For CDMA and TDMA the overlap factor is essentially unity, because, in order to avoid unacceptable crosstalk, it is usually necessary that the co-channel interference be much smaller than random noise, 2) this is achieved by having a larger cluster size, NCC. In effect, overlap factor, BOF, is traded for cluster size, NCC, and 3) system flux density, refers to the band average flux density, over the band,

W. Thus the power areal density (integrating over the entire band, W) is , by definition, ρ W. Note that with these definitions, the above relations accurately reflect the inter-system interference effects if and only if one or both of the systems are essentially uniformly spread over the band , W. Another significant difference between CDMA and non-CDMA systems in this respect, is that the adjustment of CDMA to increasing interference background from other systems is, in effect automatic; one need only throttle back the traffic loading at the source to the reduced capacity and the system operates as before, at the same ultimate fidelity, but with smaller traffic. With non-CDMA systems on the other hand, adjustment is possible to operate in increased interference at reduced capacity, but such adjustment is not inherent or automatic. Other system adjustments must be taken to adjust the system baud rate, coding, etc to recover the required SNR or Eb/No ratio. But this is of course possible, and such adaption can in principle be controlled automatically.

MULTIPLE SYSTEM, REGIONAL COVERAGE, FLUX ASSIGNMENT

Finally, we assume that multiple systems are assigned to the common band. Inevitably, this will reduce the capacity of each such band sharer relative to what would be the case if it had the band alone. If there were no flux density allocations, or agreements, then, in principle it would be possible for one user to (temporarily) "steal" most of the inherent capacity of the band by increasing his transmitted power and flux density to well above that of the others. Ultimately, however, this could only result in a mutually fruitless escalation of power and flux density. No one would gain and all would lose power efficiency. Of course this would be to the detriment not only of the band sharers but of all other incidental interference victims, such as radio astronomy services etc.

This potential must be recognized and should be provided for by firm agreements or flux density allocations administered by the FCC. For the moment we assume that such individual system flux density limits are in place by one mechanism or another, each sharer, s, being assigned a maximum flux density ρ_s. What is the resulting individual and overall capacity?

The total band flux density is given by the summation over all sharing systems of the individual system maximum flux density allocations

$$\rho_i = \sum_s \rho_{ms}$$

Each system then must satisfy its own SNR requirements by restricting its capacity to that given by equation 2 above, except that now ρ_i and $\rho_s = \rho_{ms} / BOF_s$ are given by agreement rather than necessarily set by the power limits of his own system or overall flux density limits such as the ITU limits.

For FCC purposes, the result of this sharing is best expressed in its effect on overall combined regional circuit capacity over a service region of interest such as the United States. That is, the regional capacity of the s^{th} system is:

$$M_{r_s} = \frac{\frac{\rho_{m_s}}{BOF_s} RFRF_s \, M_{max,s}}{\rho_n + \sum_s^{NS} \rho_{m_s}} \tag{5}$$

and the total regional capacity, summing over all systems is:

$$M_r = \sum_{s=1}^{NS} M_{r_s} \tag{6}$$

Now let us assume that all systems are allocated equal flux density, ρ_m so that

$$\rho_i = \sum \rho_{ms} = NS \, \rho_{ms}.$$

Then comparing 5) and 6) , the individual system capacity reduction due to sharing would be in the ratio,

$$\frac{M_{r_{s_{shared}}}}{M_{r_{s_{alone}}}} = \frac{\rho_n + \rho_m}{\rho_n + NS \, \rho_m} \geq \frac{1}{NS} \tag{7}$$

Thus the individual capacity with sharing lies somewhere between that system alone and 1/NS of that alone. Thus *if all systems were equal in terms of their individual regional capacities at the same flux limit, non-shared, then the total capacity with sharing would exceed the sum of the individual unshared capacities.* This unstated qualification is implicit in the abbreviated Loral-Qualcomm claim to this effect (Loral-Qualcomm consolidated reply, March 27, 1992, Technical Appendix, p.8). However, if one system has significantly greater regional capacity than the other sharers, as is the case for CELSTAR, then, reducing each system capacity by the roughly the same ratio, even though that ratio is greater than 1/NS, may result in a significant net loss of regional capacity.

In order to evaluate this we need to apply actual system numbers as is done in the following section.

BAND SHARING COMPARISONS

The individual system capacities are stated at various individual flux densities. To compare these and to consider sharing alternatives it is first necessary to reduce such capacities to common flux densities. The basis for doing so is equation 4. Let the system design regional capacity be denoted $M_{s,o}$ at system flux level ρ_o with no sharing. Then, at a non-shared system flux level ρ_m the system regional capacity from Equation 4, scales to

$$M_{r_{s_{alone}}}(\rho_m) = \frac{\rho_m}{(\rho_n + \rho_m)} \frac{(\rho_n + \rho_o)}{\rho_o} M_s(\rho_o) \qquad (8)$$

and the Regional capacity of the s^{th} system in the sharing mode at uniformly allocated maximum flux, ρ_m is given by, from 7:

$$\boxed{M_{r_{s_{shared}}}(\rho_m) = \frac{\rho_m / \rho_n}{(1 + NS\ \rho_m / \rho_n)} \frac{(1 + \rho_o / \rho_n)}{\rho_o / \rho_n} M_s(\rho_o) \qquad (9)}$$

Finally, the total regional capacity is simply the summation of equation (9) over all systems.

For the non-CDMA waveforms for which self-interference is not directly a capacity reducing issue (only through the necessary cluster size) this reduces simply to:

$$\boxed{M_{r_{s_{shared}}}(\rho_m) = \frac{\rho_m}{\rho_o} M_s(\rho_o) \qquad (10)}$$

Thus the system-by-system regional capacity and total regional capacity can be calculated knowing only the system capacities alone for any given ρ_o s and the flux allocations.

DESCRIPTION OF THE SPREADSHEET

The following spreadsheet carries out several example calculations and allocations according to these principles to illustrate the results of various flux density allocation strategies.

In the left part of the upper half of the spreadsheet are the basic comparative data for several competing systems. For each system,m the first two columns are the design claimed capacity and corresponding flux density, all for the critical satellite to user downlink. In order to start off on an even footing, the design capacities are first adjusted, in column 3 to a common, reference flux density. That flux density. For computational convenience and clarity, that reference flux is taken as the isotropic flux, ρ_n, corresponding to reference thermal noise density, kTo with To at 290 deg K. This turns out to be -138.6 dBW/m^2/4kHz, 5.4 dB above the ITU limit of -144. In other words, ρ_n is the flux that would provide an available power output spectral density equal to kTo with an isotropic antenna at 2490 MHz, the S-Band down-link frequency of interest. Notice that all the listed current applicants with the exception of Constellation's Aries exceed the ITU limit by sometimes significant amounts. These limits do not in all cases agree exactly with applicant's claims but are based upon stated EIRP, minimum range, and bandwidth.

The normalized circuit capacity, all at the same, refereence capacity in coliumn 3 gives a fairer comparitive view of the relative spectral density efficiency of the contenders. This is in US circuits per unit reference flux density, (units of -138.6 dBW/m^2/4kHz). Notice for example that IRRIDIUM which has a relatively high circuit capacity achives that at least partly at the expense of a relatively large Flux Density. IRRIDIUM is not considered further in the sharing comparisons largely because of the almost total incompatibility, as CELSAT views it of band sharing with a system time duplexed between up and down links as is IRRIDIUM. AMSC is not used in the comparison because as far we are aware they have not applied for spectrum in the 2483.5+ band which is the particular target of the rest of the proposed sharers.

In the several colimns of the right-hand top part of the spreadsheet are the hypothetical flux density allocations, given in terms of power flux density expressed as a factor times the defined reference (isotropic thermal noise) flux, -138.6 dBW/m^2/4kHz. For example, column 4 is a sole allocation of 1 unit to CELSTAR.

In the row called total interference we have the summation of all flux allocations, in this case, just 1 reference flux density unit. Since we have chosen thermal eqivalent flux as the reference, this line is the denominator in the first term in equation 9.

In the bottom half of the spreadsheet we have the individual system capacities under shared use. In this case, since there is no sharing and since CELSTAR is allocated unit flux, the CELSTAR component capacity is the same as the normalized CELSTAR capacity in column 3 as is the bottom line total US capacity.

In column 5 we illustrate the effect of a reduced flux, sole allocation. The allocation factor of 0.3 in this case is just equivalent to the ITU flux limit of -144. Notice that the capacity is reduced to 30,900 circuits, 46% of the unit flux capacity.

In column 8 we show the effect of band sharing on an equal flux density between ELLIPSO, ODYSSY, ARIES, and AMSC. The normalized capacity of each system is reduced by two factors, first because its own allocated flux density is less than the normalized capacity, and except for ARIES, less than the design capacity. Total US capacity is 3027 circuits, well under the design capacity of either GLOBALSTAR or ODYSSY.

In column 9 we see the effect of adding CELSTAR to this unit allocation on an equal allocation basis. Because of CELSTAR's far superior normalized capacity, the overall US capacity comes up to 18,500 circuits, six times the capacity without CELSTAR.

It may be argued that a policy of allocating flux on an equal basis may not adequately encourage future designs that will emphasize flux as the critical feature of flux normalized efficiency. Column 10 is an experiment in allocating flux in the same total amount as column 9, not equally, but rather in *proportion* to flux density efficiency, that is proportional to US circuits for unit flux density allocation. In this case, of course, CELSTAR would realize the major share of the allocation and the US capacity would be 68,800 circuits. Not only is this nearly twice the capacity of an equal allocation, but it would tend strongly to encourage other sharers or new sharers to develop more flux efficient system proposals.

IN SUMMARY

These proposals will be claimed self-serving by other contenders. But it is hoped that they will be recognized as much more than that.

The era of band sharing is here. CELSTAR of course hopes to be a part of that era. But new regulations and approaches to allocation are called for. The radio frequency spectrum must be seen to have acquired a new dimension, flux density, in which allocation is as important as the allocation of frequency if the full potential benefits of band-sharing are to be realized.

It is hoped that this monograph may offer some new insights into the ramifications of various flux density allocation policies and how they may contribute to the FCC objectives of managing the RF spectrum to the maximum benefit of its owners.

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SHARING S-BAND DOWN-LINK   REF FD : -138.6 dBW/m2/4kHz = kTo ISOTROPIC @2490 MHz
5.4 dB above -144 ITU LIMIT

COL NO:	1	2	3	4	5	6	7	8	9	10
SYSTEM	US CKTS DESIGN #	@ FD DESIGN dBW/m2/	US CKTS @REF FD #	S H A R E x REF FD						
CELSTAR	60905	-139.4	67064	1.00	0.29				0.29	1.24
IRRIDIUM	4400	-132.1	2693			1.00				
ELLIPSO II	864	-136.4	692					0.29	0.29	0.01
ODYSSY	4600	-133.8	3062					0.29	0.29	0.06
ARIES	50	-149.9	362					0.29	0.29	0.01
AMSC	3000	-130	1707							
GLOBSTAR	6500	-139.4	7157				1.00	0.29	0.29	0.13
TOTAL INTERFERENCE , x REF FD				1.00	0.29	1.00	1.00	1.16	1.45	1.45

INDIVIDUAL SYSTEM SHARING CAPACITIES

	4	5	6	7	8	9	10
CELSTAR	67064	30153	0	0	0	15876	67959
IRRIDIUM	0	0	2693	0	0	0	0
ELLIPSO II	0	0	0	0	186	164	7
ODYSSY	0	0	0	0	822	725	142
ARIES	0	0	0	0	97	86	2
AMSC	0	0	0	0	0	0	0
GLOBSTAR	0	0	0	7157	1922	1694	774
TOTAL US CAPACITY, ckts	67064	30153	2693	7157	3027	18545	68884

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Education:

B.S.	Stanford	1947
E.E.	Stanford	1949
Ph.D.	Stanford	1954

Member:

IEEE	Phi Beta Kappa
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Publications:

20 Published papers and articles on radio propagation, noise, digital signal processing, and non-linear filtering. Over 800 project reports.

1983 - Present Radio Science
1957 - 1983 Communications Research Laboratories
Consultant to Government and industry in the field of Radio Science.

1956 Interstate Electronics Corp. Founding member and chief project engineer. Missile and Test Range Instrumentation.

1952 - 1956 Ralph M. Parsons Company. Chief Project Engineer. Missile and Test Range Instrumentation Systems and Analysis.

1951 - 1952 Parsons Aerojet Company, Patrick Air Force Base. Senior engineer, Test range metric systems design and analysis.

1947 - 1951 Stanford University Research Assistant. VLF Ionospheric research.

SUPPLEMENTAL APPENDENDIX -- F

CELSAT 'S COMMERCIAL VIABILITY IS ASSURED

By

Albert H. Frazier, Jr.
Vice President, CELSAT Business Development

The market for cellular service has been firmly established during the past decade with over 7.5 million subscribers and a 43% growth rate in the United States at the end of 1991. Data from Eastern Research Corp. indicates that one of the fastest growing segments of wireless communications will be the personal or consumer market. They predict that one out of three cellular phones sold in the United States will be for non business communications. Furthermore, those who use cellular phones primarily for business purposes have increased the number of personal calls they make, particularly those with portable phones, which now represent the majority of phones purchased and as much as 80% of all cellular phones sold in some markets.

There were 12 million pagers in use at the end of 1991. The annual growth rate for pagers has averaged 15-20% over the past five years. The industry achieved this growth rate in 1991 despite the recession and the predictions by "so called" experts that pager growth would decline and the market would be cannibalized by cellular phone users. In fact, quite the opposite has occurred, as many cellular users also subscribe to paging services. Many subscribers to both services use pagers to screen their cellular calls. Paging has also been able to attract users in new market segments. For example, pagers have become a particularly attractive consumer product for many young mobile adults. One particularly bright market segment is the rapid growth of nationwide paging services whose subscriber numbers more than doubled in 1991.

Wireless data represents one of the markets poised for extremely rapid growth. At a recent wireless data conference, Gib Hoxie of Booz Allen and Hamilton, forecast an installed base of 30 million portable computer devices in the United States by the year 2000. He went on to indicate that roughly 13 million of these notebooks, pen-based and personal intelligent communicator (PICs) devices would have wireless communications capability. Celsat's ability to offer low to high speed data rates and attractive price points create an ideal network platform for many of these potential users.

Cellular's Evolutionary Outlook:

Industry experts generally feel that the increased capacity and efficiency of digital cellular systems will reduce crowding on the airwaves and stimulate customer demand. The following are a few examples of recently published statements regarding the cellular demand outlook and the impact of digital technology:

- "There are certain downtown areas or heavily-traveled highways where usage is so high at, say, rush hour that calls just get blocked," says Gregory Vogt, chief of the FCC's Mobile Services Bureau.
- Andrew Czernek, vice president of marketing at Zenith Data Systems, says digital networks would allow cellular data transmissions to at least match the regular phone network in speed - "I would expect dramatic 30% to 100% type increases in sales of laptop computers."
- Clifford A. Bean, a mobile phone analyst at Arthur D. Little, believes the new (digital) technology is expected to tighten security for cellular calls - "communications will be more private than with current analog systems, which you can listen in on with a scanner."
- Maxine Carter-Lome, a vice president of Cellcom Corp., a leading cellular communications reseller, states "Despite the slowing down of the economy, there is no slowing down at all in subscribers growth...Growth is so steady in major cities that air capacity is reaching its limit. Some of the major markets are experiencing problems -- Los Angeles certainly does. Chicago and New York have problems, although less drastic..."
- Robert Rosenberg, director of analytical services at Eastern Research Corp. in Parsippany, N. J., states "As the ultimate personal communications instruments, portables have a brighter future than transportables. But other manufacturers besides Motorola must find ways to extend battery life while further reducing bulk, weight and cost. They must also overcome the interference problems created when low-power portables are used inside buildings."

These perspectives from industry experts indicate that unsatisfied demand exists for cellular and that cellular is on an evolutionary course to PCS. In fact, over time Cellular may adopt many of the features proposed in Celsat's hybrid space and ground/microcell system.

Wireless Demand Outlook:

Testimony from the FCC's En Banc Hearing on Personal Communications Services provides substantial evidence and strong agreement regarding the huge market potential for the array of wireless services available with Celsat's HPCN concept.

Craig McCaw of McCaw communications forecast that there will be "in excess of 40 million cellular subscribers by the end of the decade."

Dr. Donald Cox on behalf of Bellcore stated: "We view PCS as a family of mass market services with many possible solutions, potentially serving tens of millions of end users. In a recent study Bellcore found that 36 percent of U. S. consumers are interested in a wireless communications service based on a shirt-pocket or purse-sized portable telephone that would be restricted to making and receiving calls within in designated zones and would not work in a moving car."

John DeFeo of US WEST states "We believe that demand for wireless personal communications will be enormous. In the U. S. alone, our projections show that up to 27% of the population will use PCS products and services by the year 2005. This means that as many as 65% of households will use wireless PCS products, as compared with the 93% of households that have wireline telephone service. In addition, there is significant demand for private applications. The total penetration number is expected to grow even larger as new PCS products are defined and developed."

John E. Major of Motorola states"...With adequate allocations and sufficient service options, technologies will be available to serve over 150 million private and public users by the year 2000....The second segment of the wireless communications industry is paging, or one-way message services. There are more than 12 million users in the U. S. today...looking ahead to the year 2000, we expect...paging will have grown most, to about 60 million. Along with growth in users, there will be significant growth in the amount of usage of services and expanded capabilities, such as interactive data, facsimile and video."

While wireless service demand projections from these four leading experts vary to some extent, they universally attest to the tremendous growth potential likely through the rest of this decade. Celsat's ability to accommodate paging, cellular, data, position determination and fax all in the same network provides an ideal platform for to deliver new and enhanced wireless services.

McCaw also indicated that "...most new personal communications services will provide only islands of coverage over a neighborhood or portions of a city, rather than continuous coverage throughout a large metropolitan area or region. It is high unlikely that they will offer public access service of any kind in agricultural or other rural areas. Yet if the new services are to prosper, their subscribers will need to access wireless communications when they roam outside their 'home' PCS environments, and they will want to do so using the same handset."

He later goes on to say, "...personal communication networks that propose to operate in the 1.8 to 2.2 GHz bands...envision using microcells that average 1000 feet in diameter. While some of these networks may offer continuous coverage of parts of markets, the economic constraints against deploying literally thousands of microcells to serve outlying areas indicate that these networks will not furnish the kind of coverage associated with 800 MHz cellular systems."

However, Celsat has the solution to this knotty problem. With a combined satellite and ground microcell network, Celsat provides economical ubiquitous coverage through satellite circuits while microcells can be added based on demand and not for coverage. Celsat allows rural America to receive the same wireless services as urban America.

Again, John DeFeo "We at U. S. WEST have spent a great deal of time listening to our customers in order to find out what they value and what their needs are. We know from our own experience and from extensive research what customers want from their communications providers. First, they want to be able to manage their time. Second, they want to be in touch. Paradoxically, they also want to be in control. And finally, they want to feel secure. We believe that a continuum of products and services exhibiting various combinations of functionality and consumer value provides the answer to meeting these four basic needs...PCS will allow customers to have simple access to ...a wide range of functionality, including one-way, two-way and combinations, customers will be able to mix and match products and services in order to best meet their needs."

Celsat's independent research of what customers desire in wireless communications concurs with the research of US WEST. That is why we proposed the variety of services with a single secure handset. Celsat's integrated space/ground Celstar™ system address these needs better than any single ground or space wireless network can.

In US WEST's view, PCS is not a single new service, but a broad continuum of both existing and new services that meet customer demands for mobile and fixed communications, including paging, cordless telephone (CT-1), telepoint-like service (CT-2), limited-mobility PCS service (Enhanced CT-2), PCN, cellular, and satellite services, landline telephone service, and other services yet to be defined.

US WEST has conducted economic modeling of the cost of using various alternative networks for PCS infrastructure support. This analysis showed that a microcell network based on either cable or local exchange carrier infrastructure would likely be able to provide service at a lower investment per subscriber than a digital conventional cellular system. In designing a PCS network...there may be some parts of the network infrastructure that would be most logically based on microwave and other alternative transmission facilities as well."

Conclusion:

Clearly, Celsat's satellite based system represents a superior alternative transmission facility. In fact, Celsat's Celstar system offers an extremely flexible network platform that allows multiple markets and market segments to be addressed. The mobile voice, data, position determination, paging, multimedia and video communications market, including general public as well as business users, will be the primary markets addressed. Celsat offers an innovative and unique platform where the full potential of PCS can become a reality.

* * * * *

CERTIFICATE OF SERVICE

This is to certify that a copy of the foregoing Consolidated Reply of CELSAT has been served this date by depositing the same in the U.S. mails, First Class postage prepaid, addressed to the persons listed on the attached service list. In addition, a copy has been served on Regulatory Counsel for the United States Telephone Association, at 900 19th Street, N.W., Suite 800, Washington, D.C. 20006, who was omitted from the list.

Victor J. Toth

April 23, 1992

VERIFIED DECLARATION OF DAVID OTTEN

I hereby certify that, as President and C.E.O. of CELSAT, Inc., I am familiar with the foregoing Reply and Opposition and reviewed its contents thoroughly. As to the factual statements and representations made therein I believe them to be true and correct to the best of my knowledge and belief.

David Otten
President

April 23, 1992

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